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EXECUTIVE SUMMARY

BRUCE GS 'A' COLD WATER INTAKE STRUCTURE CATHODIC PROTECTION SURVEY AND EXAMINATION OF CORROSION COUPONS

A.C. Headon

The cathodic protection system installed on the Bruce 'A' intake structure in 1979 was surveyed in June 1985 and was found to be operating satisfactorily. At the same time, test coupons installed in 1981 and 1983 to monitor general corrosion, crevice corrosion and cathodic protection were removed for examination.

The corrosion was localized on the unprotected test coupons in the form of pits giving an average corrosion rate of 0.03 mm/y for the 24 months exposure and 44 months exposure. Corrosion in the test crevices was slight. The average corrosion rate for the cathodically protected coupons was 0.01 mm/y for a 44 month exposure.

Although the average corrosion rate of the unprotected test coupons is low, it is recommended that these studies should be continued so that the unpredictable pit growth can be monitored and re-evaluated each year.

To improve the operation of the cathodic protection system supplying current to the highly stressed areas of the structure, tubercles were cleaned from the steel surface near the anodes. The effect on corrosion control of this cleaning will be examined in the summer of 1986.

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BRUCE GS 'A' COLD WATER INTAKE STRUCTURE CATHODIC PROTECTION SURVEY AND EXAMINATION OF CORROSION COUPONS

A.C. Headon

The cathodic protection system installed on the Bruce 'A' intake structure in 1979 was resurveyed in June 1985. At the same time, test coupons installed in 1981 and 1983 to monitor general corrosion, crevice corrosion and cathodic protection were removed for examination. It was found that the cathodic protection system is reducing the corrosion rate of the bare carbon steel near the anodes. Based on the test coupons, the general corrosion rate is about 3X the cathodically protected corrosion rate.

INTRODUCTION

A cathodic protection system using sacrificial magnesium anodes was installed in 1979 on the bare carbon steel intake structure to protect the critical locations from the corrosion that had been observed on plate and bolt components in 1978 (Research Division Report B78-43-K).

The location of the anode assemblies used and the assembly instructions to be followed by the divers attaching the anode assemblies are given in Generation Projects Division Report CES No 79-8.

Results of previous surveys of the cathodic protection system are given in Research Division Report 80-526-K and a memorandum to Mr. W.B. Chong, Bruce Engineering - Civil, Research Division File 827.3 dated June 4, 1981.

In 1981, test coupons were installed on the intake structure on three legs at two levels to monitor general corrosion, crevice corrosion and cathodic protection.

Details of the coupons, test plates, location and mounting methods are given in the following drawings of the Design and Construction Branch, Generation Services Department:

NK21-1G-23250-1200
NK21-1G-23250-1201
NK21-1G-23250-1202
NK21-XG-23250-1203
NK21-1G-23250-1204
NK21-1G-23250-1205
NK21-XG-23250-1206
NK21-1G-23250-1207
NK21-0G-23250-1208
NK21-XG-23250-1209
NK21-1G-23250-1210
NK21-0G-23250-1211
NK21-1G-23250-1212
NK21-1G-23250-1213
NK21-1G-23250-1075

In 1983, the structure was resurveyed and a set of test coupons that had been installed for 20 months was removed for examination (Research Division Report 84-81-K).

In this report, the results of the 1985 structure survey are given. Sets of test coupons that had been installed for 24 months and 44 months were removed, cleaned and their corrosion rates calculated.

UNDERWATER POTENTIAL SURVEY

Method

To conduct an underwater potential survey, a lead is connected to the structure at some convenient location and brought back to the surface. This lead is attached to the negative terminal of a high input impedance voltmeter. A copper/copper sulphate reference electrode is attached to a second lead from the positive terminal of the voltmeter. A diver carries the reference electrode to designated points on the structure so that the potential of the various points can be measured.

Observations

The potential readings for Leg Supports V4 and V5 are given in Tables I and II. The locations of the numbered test points are shown on Figure I.

Discussion

A potential of -0.85 V or more negative usually indicates areas of complete protection.

A potential of -0.72 V prevents pits and crevices from growing and a potential of about -0.60 V indicates that some protection is being received.

The potentials of the magnesium anodes indicate that they are operating satisfactorily. The steel near the anodes is either well protected or receiving some protection. The steel midway between the anodes, however, is likely not receiving sufficient current to reduce the corrosion rate by a significant amount.

REMOVAL AND EXAMINATION OF TEST COUPONS

General Corrosion Coupons, Level A and B - V2, V6, V10

A total of 12 general corrosion coupons were removed from Legs V2, V6 and V10 at levels A and B on June 26 and 27, 1985. Some of these coupons had been installed for 24 months and some had been installed for 44 months. These coupons were cleaned and examined at the Research Division.

The calculated average corrosion rate for the coupons exposed for 24 months was 0.033 mm/y. The corrosion was in the form of localized pits* with a maximum pit depth of 0.45 mm and a diameter of 12 mm.

The calculated average corrosion rate for the coupons exposed for 44 months was 0.027 mm/y. The corrosion was in the form of localized pits with a maximum pit depth of 1.2 mm and a diameter of 5 mm (Photograph No 1).

Crevice Corrosion Coupons, Level A - V2, V6, V10

A total of three crevice corrosion coupons exposed for 44 months were removed from Legs V2, V6 and V10 at level A. There was almost no crevice corrosion associated with the test crevice produced by bolting a small rectangular test coupon to a larger rectangular test coupon. There was, however, more crevice corrosion under the four nylon split bushings that held the samples in place (Photograph No 2).

There was considerable localized corrosion of the test coupons around washers, nuts and bolts holding the coupons together. It was thought that this localized corrosion when first observed in 1983 was galvanic in nature due to the difference in composition of the test coupon and the washer, nut and bolt combination. The coupons are CSA G40.21-44W and the nuts and bolts are A325. The washers are standard hard grade.

*Pits are used here to mean the deep points of corrosion penetration, whether they are true pits which are deep and narrow, or only wide, shallower depressions.

A test conducted at the laboratory to measure the current flow between the test coupon and the nut, bolt and washer combination showed that there was a very small current flow with the nut, bolt and washer combination anodic to the coupon. This direction of current flow would not produce the corrosion observed on the coupons.

Although laboratory test conditions were not exactly the same as in the field, the trends should have been the same.

The corrosion that occurred around the washers must have been enhanced by the deposits that collected around the edge of the washers.

Cathodically Protected Coupons

A total of three cathodically protected coupons exposed for 44 months were removed from Legs V2, V6 and V10 at level B.

The average corrosion rate of these test coupons was 0.011 mm/y. The pits are much less numerous on these coupons than on the unprotected general corrosion coupons and the corrosion rate is about 1/3 that of the unprotected coupons.

Enhanced corrosion of the coupons occurs around the mounting bolts and washers and around the epoxy coated mounting posts. This corrosion is similar to the corrosion that occurred around the washers on the crevice corrosion coupons. The low level of cathodic protection has not controlled this corrosion (Photograph No 3). The amount of metal loss due to this enhanced corrosion after 44 months of exposure is very similar to the amount of metal loss after 20 months of exposure, particularly for the cathodically protected coupons.

This form of corrosion will be monitored on future surveys.

Anode on Steel Sheet, Level A - V4, V8

The steel sheet (CSA G40.21-44W) is somewhat elliptical in shape 183 cm (72") long by 51 cm (20") at its widest. The test sheet mounted at Level A, V4 has the long dimension of the "ASARCO" T53 magnesium anode parallel to the long dimension of the sheet. The test sheet mounted at level A, V8 has the long dimension of the anode perpendicular to the long dimension of the sheet (Figure II).

The potentials of the sheets versus a $Cu/CuSO_4$ reference electrode were measured at a number of locations before they were inspected. The sheet at level A, V4 was inspected on the structure, the sheet at level A, V8 was removed for inspection. The location of the numbered test points are shown in Figure II. The measured potentials are given in Table III.

The potentials of the steel sheet of both V4 and V8 at test points 2 and 3 are receiving cathodic protection current. Based on the measured potential, number 4 test points are receiving little cathodic protection. The potentials of the anodes, test points 1, show that they are operating satisfactorily.

The surface of the sheet at level A, V8 was inspected after removal from the structure. Most of the surface was covered with a hard protective calcareous coating before cleaning (Photograph No 4). After cleaning, some pitting was found as shown in Figure II and Photograph No 5. The extent of pitting was similar to that found in the 1983 inspection. The coal tar epoxy on the mounting brackets for the anodes was in excellent condition.

The surface of the sheet at level A, V4 was inspected underwater after cleaning. If Photograph Nos 6 and 7 of this report are compared with Photograph Nos 5 and 6 in the 1983 Report 84-81-K, it will be seen that the corrosion has not spread markedly.

Removal of Tubercles Near the Anodes

In the report of the 1983 inspection, the positive results of an analysis of the Bruce GS 'A' water intake structure for sulphate reducing bacteria under tubercles was discussed. As the low level of cathodic protection provided by the magnesium anodes would be unable to stop sulphate reducing bacteria attack that is occurring under tubercles, it was recommended that the structure should be cleaned near the anodes during the next survey. These anodes are located at critical highly stressed areas of the structure.

In 1985, this cleaning was done at all the anode locations. On Leg 5 (L5)*, 17 coloured photographs were taken at 5 different locations (Figure III). A selection of these photographs is attached (Photographs 8-13). A red and white sign was attached to the structure at each photographic location to ensure positive identification during future inspections.

All photographs and a more detailed description of their location are being kept on file at the Research Division.

In Service Visual Inspection

An in-service visual inspection of the structure was carried out by the divers with the following observations:

1. The post-tensioning anchorages of the concrete roof have not corroded. The concrete roof is crack free.

*The abbreviations "L" and "V" have both been used for "Leg" in this report.

2. The bolted connections are in satisfactory condition with less enhanced corrosion around the nuts and bolt heads than on the test coupons.

3. The cathodic protection units and the corrosion testing units are well fastened to the structure.

4. The corrosion of the structure is less near the anodes than on the unprotected structure.

5. The corrosion on the structure is less severe than the corrosion on the test coupons. The density of the pits is less on the structure than on the test coupons.

CONCLUSION

The calculated corrosion rates from the weight loss of the general corrosion test coupons and the cathodically protected test coupons, since the start of this study are given in the following table:

	20 Months Oct 81-Jun 83	24 Months Jun 83-Jun 85	44 Months Oct 81-Jun 85
General Corrosion	0.03 mm/y	0.033 mm/y	0.027 mm/y
Cathodically Protected	0.02 mm/y		0.011 mm/y

The corrosion was mainly localized pitting* with the following maximum pit depth and diameter.

	20 Months	24 Months	44 Months
Maximum Pit Depth	0.9 mm	0.45 mm	1.2 mm
Diameter	6 mm	12 mm	5 mm

The corrosion rate for general corrosion seems to have stabilized at about 0.03 mm/y. The corrosion rate of cathodically protected coupons is being reduced with time.

The general corrosion rate for the structure could be a little less than the corrosion rate for the test coupons for the following reasons:

* Pitting is used here to mean the deep points of corrosion penetration, whether they are true pits which are deep and narrow, or only wide, shallower depressions.

1. There was enhanced corrosion around the four nylon split bushings that hold the test coupons on the racks (Photograph Nos 1 and 2).

2. The test coupons were sheared from sheets leaving the edges cold worked. The edges of the test coupons were subject to end grain corrosion.

3. The cathodically protected test coupons had enhanced corrosion around the mounting bolts and washers and around the epoxy coated mounting parts fastening them to the racks (Photograph No 3).

The magnesium anodes attached to the structure are able to reduce the rate of corrosion of the highly stressed areas of the structure. The anodes are able to modify the corrosion up to three feet away.

1986 Test Program

Although the average corrosion rate of the unprotected test coupons is low, it is recommended that these studies should be continued so that the unpredictable pit growth can be monitored and re-evaluated each year.

Test coupons when originally installed were to be removed after 1, 3 and 10 years of exposure. One year general corrosion coupons were to be removed and replaced with unexposed ones each year and the two steel sheets with anodes attached were to be removed on a yearly basis.

This initial schedule has not been adhered to exactly.

The one year general corrosion coupons installed in June 1985 should be removed in June 1986. It is not felt necessary to replace them as sufficient short term data will have been acquired. The long term (ten year) test coupons should be left in place. One of the steel sheets with anodes attached should be removed for examination in 1986 and a potential survey of the structure should be made at the same time.

The areas near the anodes where tubercles have been removed to expose pitted metal should be examined carefully for changes in corrosion activity. The areas photographed and signed in 1985 should be photographed again for comparison.

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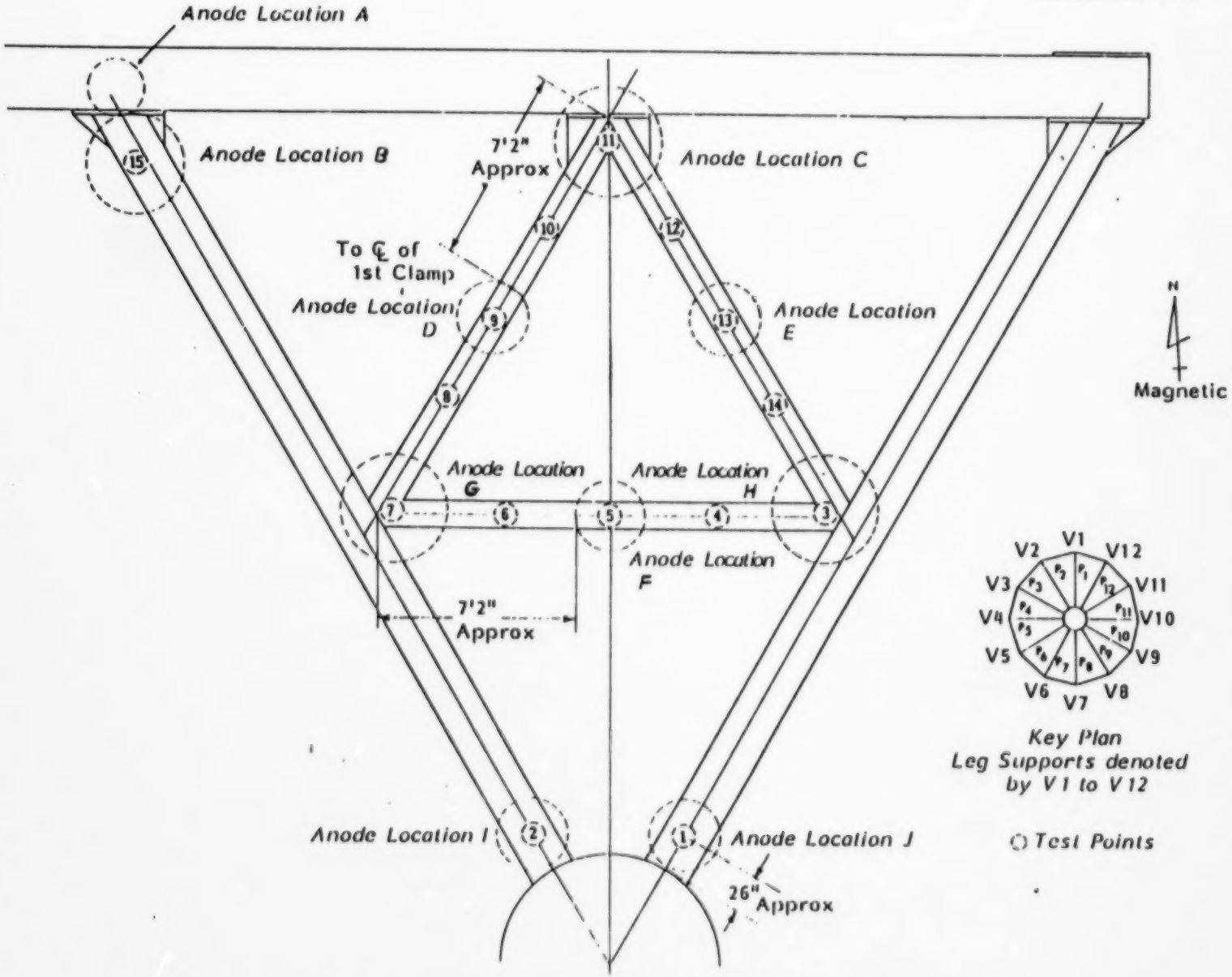
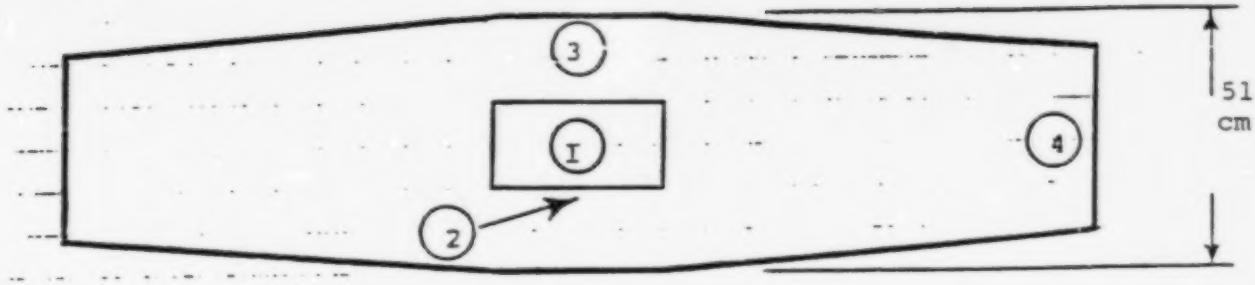
ACH:md

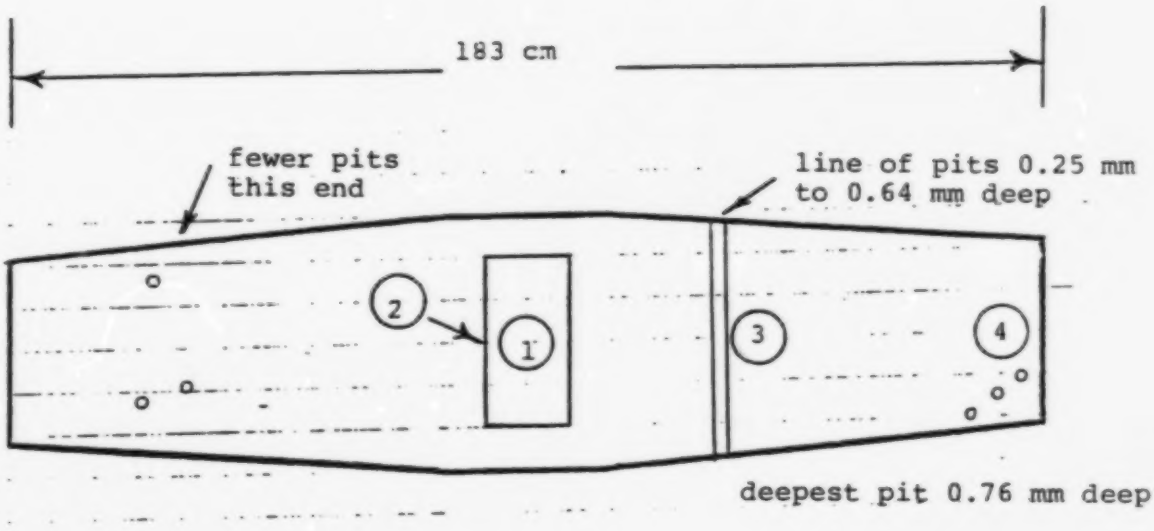


BRUCE GS 'A' CW INTAKE TUNNEL INTAKE STRUCTURE REHABILITATION
PROTECTIVE ANODE LOCATIONS CATHODIC PROTECTION

FIGURE I



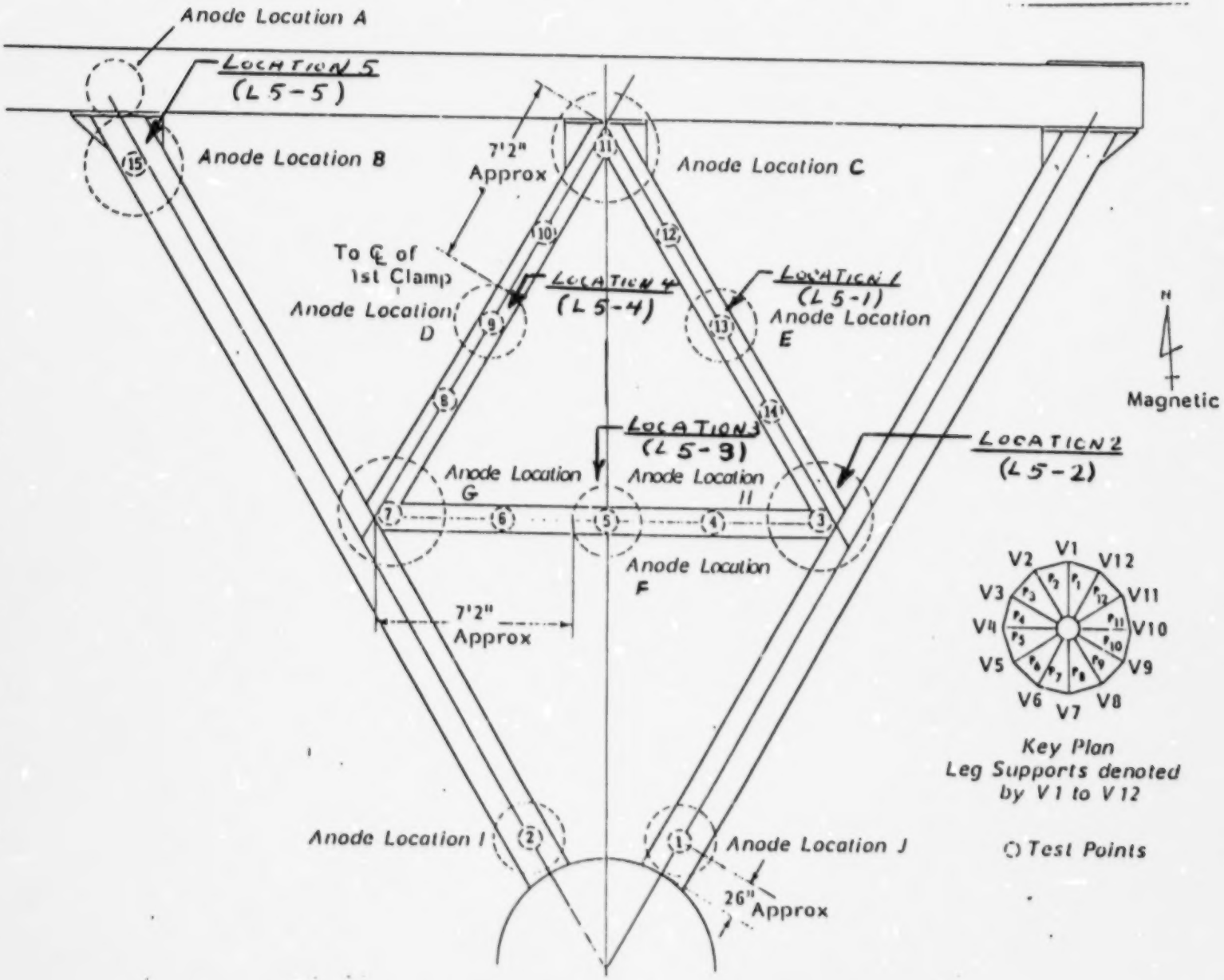
LEVEL A V4



LEVEL A V 8

ANODE ON STEEL SHEET

FIGURE II



LOCATION AND IDENTIFICATION OF PHOTOGRAPHS TAKEN DURING STRUCTURE CLEANING LEG 5 (L5)

FIGURE III

TABLE I

LEG SUPPORT V4

Potential in Volts re $Cu/CuSO_4$ Reference Electrode

Test Point (See Figure I)	Magnesium Anodes	Structure Near Magnesium Anodes	Structure Between Magnesium Anodes
1	-1.4	-1.04	
2	-1.32	-0.93	
3	-1.45	-0.85	
4			-0.64
5	-1.33	-0.99	
6			-0.60
7	-1.36	-0.99	
8			-0.50
9	-1.41	-0.96	
10			-0.51
11	-1.38	-0.96	
12			-0.55
13	-1.39	-0.98	
14			-0.54
15	-1.41	-0.73	

TABLE II

LEG SUPPORT V5

Potential in Volts re $Cu/CuSO_4$ Reference Electrode

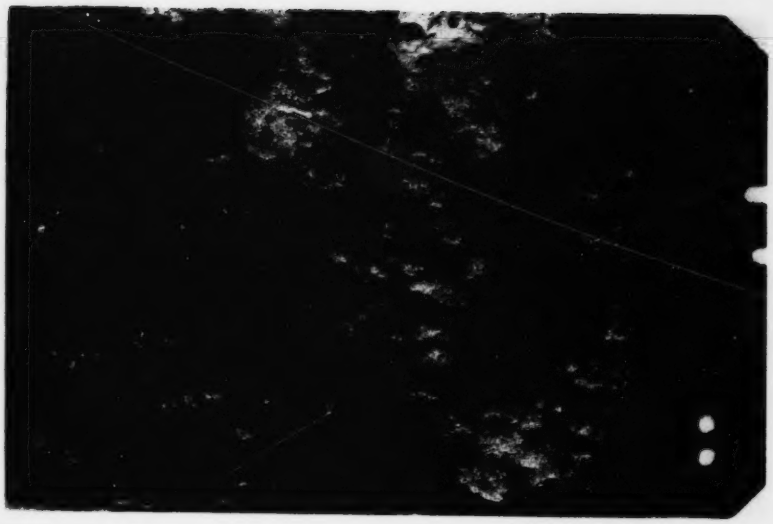
Test Period (See Figure I)	Magnesium Anodes	Structure Near Magnesium Anodes	Structure Between Mangesium Anodes
1	-1.35	-0.97	
2	-1.34	-1.04	
3	-1.33	-0.77	
4			-0.59
5	-1.32	-0.98	
6			-0.60
7	-1.33	-0.98	
8			-0.54
9	-1.37	-0.86	
10			-0.52
11	-1.41	-0.88	
12			-0.51
13	-1.33	-0.88	
14			-0.52
15	-1.40	-0.67	

TABLE III

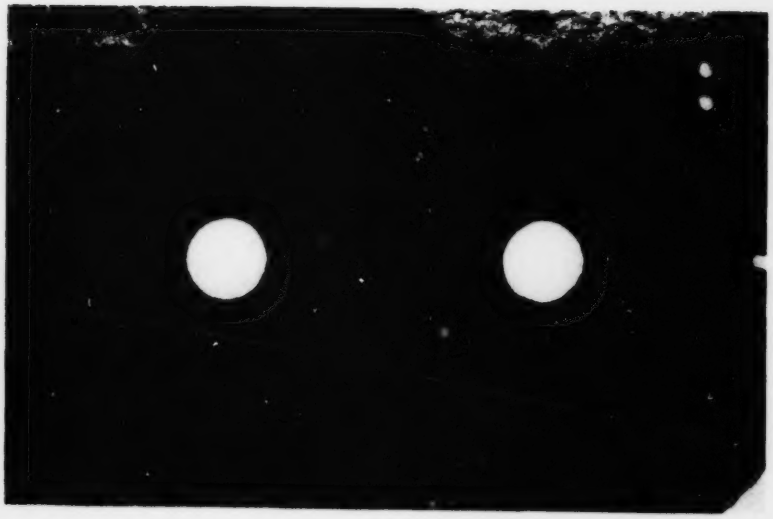
ANODE ON STEEL SHEET
POTENTIAL IN VOLTS RE $Cu/CuSO_4$ REFERENCE ELECTRODE

Test Point (See Figure II)	Level A - V4
1	-1.32
2	-0.91
3	-0.90
4	-0.55

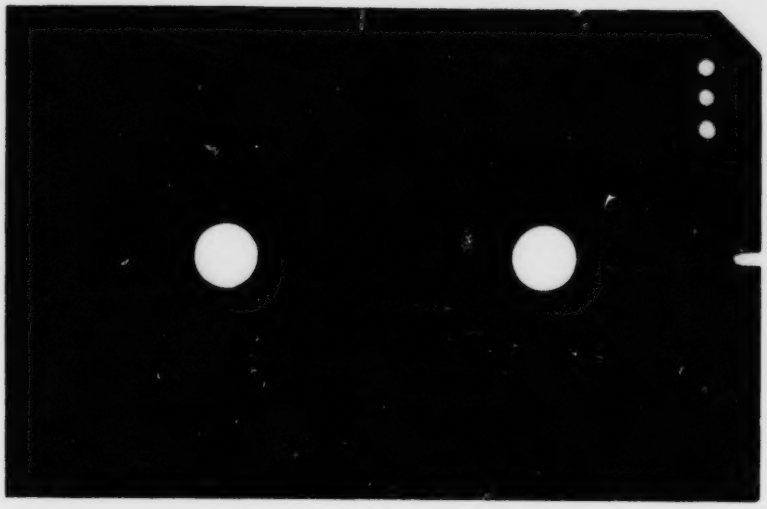
	Level A - V8
1	-1.35
2	-0.99
3	-0.85
4	-0.57



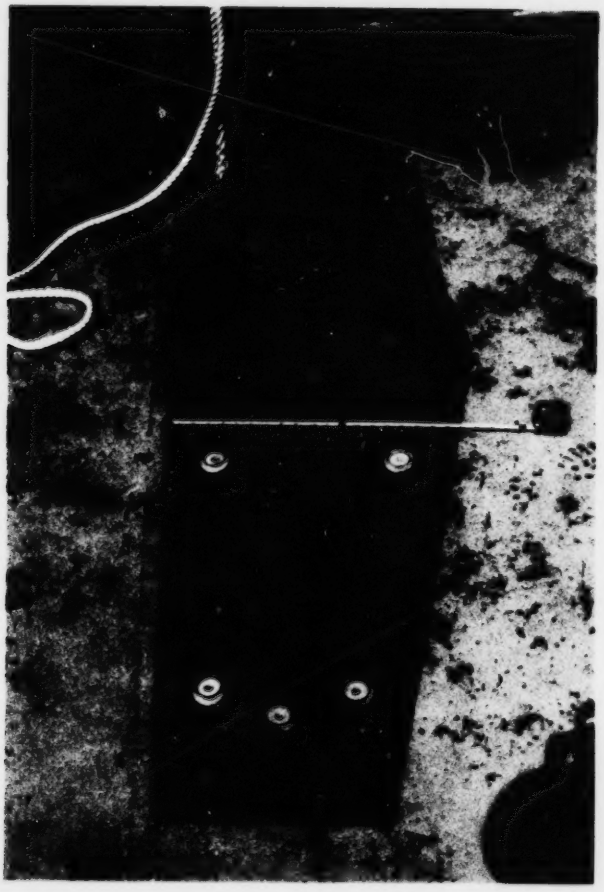
PHOTOGRAPH NO 1. GENERAL CORROSION TEST COUPON 44 MONTHS EXPOSURE.



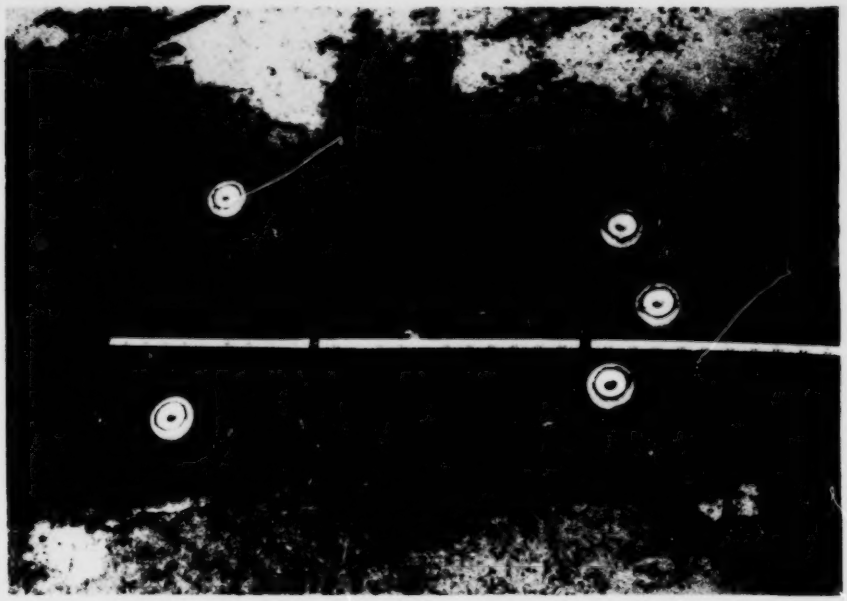
PHOTOGRAPH NO 2. CREVICE CORROSION TEST COUPON 44 MONTHS EXPOSURE.



PHOTOGRAPH NO 3. CATHODICALLY PROTECTED TEST COUPON 44 MONTHS EXPOSURE.



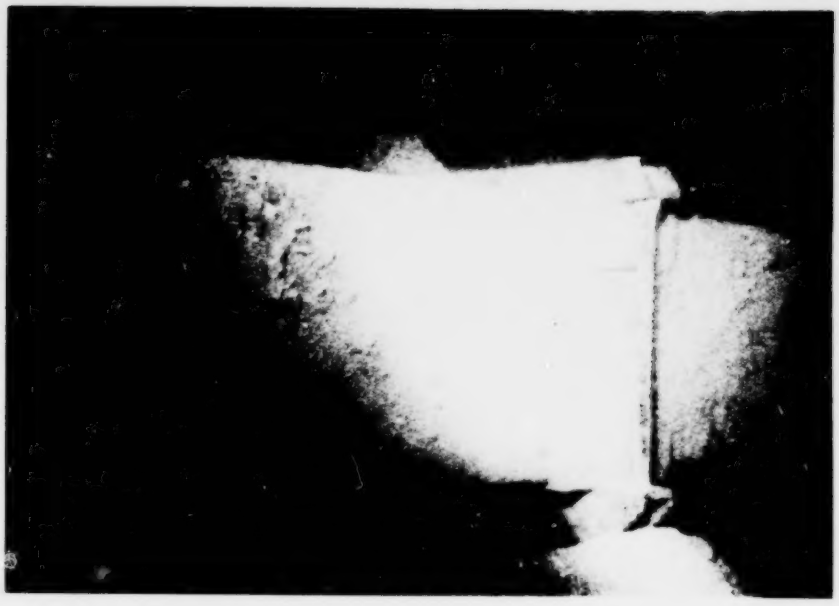
PHOTOGRAPH NO 4. ANODE AND STEEL SHEET MOUNTED AT LEVEL A, V8



PHOTOGRAPH NO 5. A VIEW TOWARDS ONE END OF THE SHEET, LEVEL A, V8

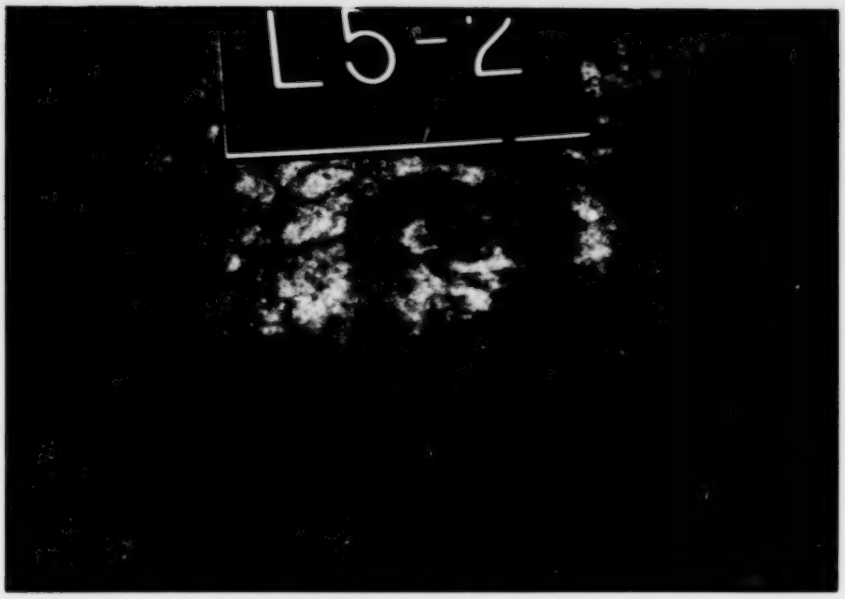
PHOTOGRAPH NO 6. AN UNDERWATER VIEW TO ONE END OF THE SHEET, LEVEL A, V4.

PHOTOGRAPH NO 7. AN UNDERWATER VIEW TOWARDS THE OTHER END OF THE SHEET, LEVEL A, V4



PHOTOGRAPH NO 8. LOCATION L5-1 BEFORE CLEANING.

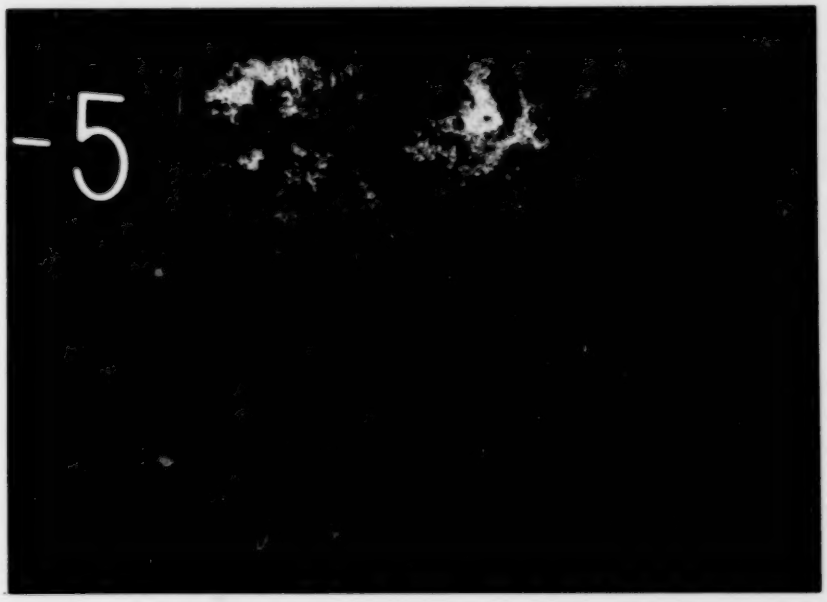
PHOTOGRAPH NO 9. LOCATION L5-1 AFTER CLEANING.



PHOTOGRAPH NO 10. LOCATION L5-2 AFTER CLEANING.

PHOTOGRAPH NO 11. LOCATION L5-3 AFTER CLEANING.

PHOTOGRAPH NO 12. LOCATION V5-4 AFTER CLEANING.



PHOTOGRAPH NO 13. LOCATION V5-5 AFTER CLEANING.